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TOE GRAPHAESTHESIA AS A DISCRIMINATOR OF BRAIN IMPAIRMENT: THE OUTSTANDING FEET FOR NEUROPSYCHOLOGY[1]

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Summary.—Because of the vulnerability of the medial surfaces of the cerebral hemispheres to the consequences of shear forces, we hypothesized that quantitative sensorimotor deficits for the feet would be strong indicators of general brain dysfunction. On the basis of the Halstead-Reitan Impairment Index, 28 adults who had received closed head injuries were assigned to perfectly normal, normal, or (mildly to severely) impaired groups. Foot tap and finger tap as well as agnosia and graphaesthesia for the fingers and toes were measured. Deficits in toe graphaesthesia were the most powerful group discriminator. Potential usefulness of haptic/motor, finger/toe comparisons for recording the progress of degenerative diseases, such as AIDS, is also suggested.

Inferential strategies for neuropsychological assessment implicitly assume that unique variance exists between specific tasks and specific spatial domains of brain function. The majority of classic neuropsychological tasks from which we infer brain dysfunction involve the dorsolateral, lateral, or ventral lateral portions of the cerebral hemispheres. Except for the potential aberrations in interhemispheric coherence because of disruptions within the corpus callosum, few neuropsychologists test for the functional integrity of the medial surfaces that are buried, but closely apposed, within the longitudinal fissure.

Classic investigations of neurobehavioral correlates have indicated that sensory representations of the toes and feet normally occur within the paracentral lobule of the parietal cortices while motor control is mediated through the immediately rostral medial frontal region. Few neuropsychologists (Peters, 1990) have considered the potential importance of toe perception. We hypothesized that significant alterations in toe identification and graphaesthesia should be conspicuous with most closed head injuries following motor vehicle accidents, given several physical factors.

The medial surface is supplied by bilateral branches of the anterior cerebral artery (ACA); in about 25% of all brains, the ACA from one hemisphere does not originate from its ipsilateral source but instead is derived from a branch that has crossed the longitudinal fissure from the ACA of the opposite hemisphere (Carpenter & Sutin, 1983). Consequently, even small shear forces could damage the angioarchitecture and produce bilateral paresis

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and impaired sensation of the lower limbs (that mimics spinal cord disease). Because the paracentral lobe is most distal from the source, this region would be especially prone to diaschisis and ischemia. Even marginal neuronal dropout could produce dramatic changes in perception given the poor (compared to the fingers) spatial resolution of the toes that in turn is determined by their limited area of representation and low neuronal density.

To test this hypothesis we examined a total of 28 (21 men, 7 women) adults (mean age = 29 years, $SD = 11$ years) who had sustained or who were strongly suspected to have sustained a closed head injury during the previous 1 to 10 years. Because there were not even marginal sex differences for any of the measures described in this study, the gender variable was ignored. The subjects were divided, according to their Halstead-Reitan Impairment Index (based on previous, complete neuropsychological assessments), into perfectly normal (0.0 to 0.1), normal (0.2 through 0.4), and impaired (>0.4) groups. There were 6, 9, and 13 subjects per group, respectively; there was no statistically significant difference in age among the groups ($p>0.05$).

The following measures were taken as described by Reitan and Wolfson (1985): finger tap (per 10 sec.), finger agnosia, finger graphaesthesia. In addition, foot tap (per 10 sec.), toe agnosia, and toe graphaesthesia were also measured. The two latter measures utilized the same procedure (numbers of trials) as had been applied to the fingers (Reitan & Wolfson, 1985). Total errors for the identification of fingers for both hands or for the identification of the toes for both feet were determined. Total errors for the detection of the randomly presented numbers 3, 4, 5, and 6 for the fingers of both hands and for the toes of both feet (potential error range 0 to 40 for fingers and toes) were obtained. The numbers were drawn on the distal tip of the fingers and the distal tip of the toes with a stylus.

To control for nonspecific or confounding variables, WAIS—R Verbal IQ, Performance IQ, Seashore Rhythm scores (total correct; maximum score = 30), and Depression scores for this scale from the MMPI (Minnesota Multiphasic Personality Inventory) were obtained from each subject's record. Descriptive statistics as well as analyses of variance and covariance and discriminant analyses were completed by SPSS^x software on a VAX 4000 computer. Because homogeneity of variance was violated in some instances, Kruskal-Wallis (nonparametric) tests were completed for all group comparisons; these results are given where appropriate.

The means and standard deviations for finger tap and foot tap and the means and standard deviations for the total (both appendages combined) numbers of errors for finger and toe agnosia and graphaesthesia tasks are shown in Table 1 for the perfectly normal, normal, and impaired (mild to severe combined) groups. There were no statistically significant group differences on finger agnosia ($F_{2,25} = 0.33$, $p>0.05$) or finger graphaesthesia

($F_{2,25} = 3.05$, $p > 0.05$; $\chi^2 = 8.83$, $p = 0.01$) or hand tap ($F = 3.03$, $p > 0.05$; $\chi^2 = 6.78$, $p < 0.05$).

The discrepancy between parametric and nonparametric analyses were not evident for the foot measures. There were statistically significant group differences for foot tap ($F_{2,25} = 5.82$, $p < 0.01$; $\eta = 0.56$; $\chi^2 = 8.08$, $p = 0.01$), toe agnosia ($F = 3.69$, $p < 0.05$; $\chi^2 = 5.98$, $p = 0.05$), and toe graphaesthesia ($F = 15.10$, $p < 0.001$; $\eta = 0.75$; $\chi^2 = 11.51$, $p < 0.01$). *A posteriori* Scheffé ($p < 0.05$) tests indicated that the impaired group displayed worse toe graphaesthesia than did the other two groups who did not differ significantly from each other.

TABLE 1

MEANS AND STANDARD DEVIATIONS FOR MOTOR AND SENSORY TASKS FOR HANDS/FINGERS AND FEET/TOES, IQS, NUMBER OF CORRECT SEASHORE RHYTHM RESPONSES AND DEPRESSION *T* SCORES FOR THREE GROUPS OF PATIENTS

Variable	Perfectly Normal		Normal		Impaired	
	M	*SD*	*M*	*SD*	*M*	*SD*
Finger Agnosia	1.3	1.8	2.1	3.3	2.5	2.7
Toe Agnosia	4.2	2.8[a]	8.7	4.0	9.1	4.0[b]
Finger Graphaesthesia	2.8	1.0	2.6	3.7	7.8	7.2
Toe Graphaesthesia	9.1	4.2[a]	11.3	5.6[a]	20.3	6.2[b]
Finger Tapping	51.7	9.1	49.5	6.3	43.2	8.3
Foot Tapping	46.5	14.0[a]	39.5	9.8	29.7	8.8[b]
Verbal IQ	109.3	17.9[a]	91.1	8.3[b]	87.5	12.7[b]
Performance IQ	104.8	11.9[a]	97.6	7.4[a]	82.8	8.9[b]
Seashore Rhythms	27.5	3.1[a]	24.4	4.0	21.5	3.9[b]
Depression	72.5	7.4	78.9	9.2	78.5	14.6

[a] vs [b] $p < 0.05$.

The means and standard deviations for the WAIS—R Verbal IQ, Performance IQ, numbers of correct discriminations for the Seashore Test, and the *T* scores for the Depression Scale are also shown in Table 1. There were statistically significant differences between the groups for Verbal IQ ($F_{2,25} = 5.78$, $p = 0.008$), Performance IQ ($F = 14.04$, $p < 0.001$), and Seashore scores ($F = 5.45$, $p = 0.01$) but not for the Depression scores ($F < 1.00$). Covariance for either WAIS—R Verbal IQ, Performance IQ, Seashore Rhythm, or Depression Scale scores, before the group comparisons were made, eliminated all of the significant group differences for sensory detection except for toe graphaesthesia ($F_{2,23} = 7.36$, $p = 0.004$); the only significant covariate was WAIS—R Performance IQ ($F_{1,23} = 11.72$, $p = 0.002$).

Discriminant analysis using only the three hand/finger (canonical correlation = 0.57) measures correctly classified 60% of the cases while the homologous measures for the toes/feet (canonical correlation = 0.77) correctly classified 77% of the cases; it did not classify any of the perfectly normal as impaired or any of the impaired as perfectly normal. The use of toe

graphaesthesia singly correctly classified 91% of the severely impaired patients. There were no statistically significant ($p > 0.05$) correlations (*rho*) between impairment scores >0.4 and any of the six foot or hand measures.

These results support our hypothesis concerning the particular vulnerability of the medial hemispheric surfaces to the consequences of shear and compressional forces and indicate that *quantitative* impairment of sensory and motor deficits of the feet/toes are more discriminative for severe brain impairment than are traditional finger measurements. Because the group differences in sensorimotor measures of the feet were still evident after initial covariance for classic indicators of disruption of processing (Performance IQ), attention (Seashore), and general malaise (Depression), an effect artifact is not likely.

There are two major applications for these results. First, differential comparisons of anterior (motor) with posterior (toe agnosia) measures may help differentiate cases in which disruptions in emotional bonding to family members occur as sequelae to the brain injury; this approach is based upon MacLean's (1990) concept that the region around the anterior cingulate region is associated with social-emotional bonding. Second, leg weakness and sensory distortions are one of the initial symptoms (Sarazin, 1991) of AIDS (acquired immunodeficiency disease). Actuarial comparisons of graphaesthesia of the toes, based upon norm-referenced samples, might be useful quantitative indicators of the neuropsychological progression of this disease.

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